«ETTORE MAJORANA» CENTRE FOR SCIENTIFIC CULTURE
ERICE INTERNATIONAL SEMINARS

• *The Collision of an Asteroid or Comet with the Earth*
28 April - 4 May 1993 - 17th Workshop

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PROFESSOR A. ZICHICHI - CHAIRMAN

CSP-93-1017

Statement of the Participants

Erice International Seminars on Planetary Emergencies

17 Workshop: The Collision of an Asteroid or Comet with the Earth

We the undersigned participated in the Erice International Seminars on Planetary Emergencies: 17th Workshop: The Collision of an Asteroid or Comet with the Earth, met in Erice Sicily from 28 April to 4 May, 1993. Following presentations and discussions on the subject of the threat to humanity from Cosmic Impact, the undersigned concur as to the following points:

1) Cosmic Impact is an environmentally significant phenomenon which has played a major role in the evolution of life on Earth.

2) In any given year there is a very low probability that a large Cosmic Impact may occur which would destroy human civilization or even a significant fraction of life on Earth. However, the threat is real and requires further internationally coordinated public educational efforts.

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3) A significant near term Cosmic Impact threat identified at the Workshop is a naturally produced atmospheric explosion of a small Near Earth Object being mistaken for a nuclear explosion, at a time and place of international tension. These events have been observed. Such an event could be misinterpreted as a nuclear attack and trigger an unfortunate reaction.

4) The gathering of additional physical knowledge on Near Earth Objects and their effect on Earth is a scientifically and socially important endeavor. These multi-disciplinary efforts should be conducted in an open coordinated international manner. Dedicated international astronomical facilities similar to the proposed Spaceguard System should be developed. The defense related assets and technologies of the former Cold War combatants can contribute to the gathering of these data, through ground and robotic space observation. These skills and technologies, necessary for any large, complex, investigation, should be well utilized now that the threat of global thermonuclear war has been reduced.

5) The study of potential mitigation systems should be continued. Many of us believe that unless a specific and imminent threat becomes obvious, actual construction and testing of systems that might have the potential to deflect or mitigate a threat may be deferred because technology and systems will improve.

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K/T-MASS EXTINCTIONS: SOME ASTRONOMICAL CONSTRAINTS

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Abstract. The observed patterns of mass extinctions at and around the K/T boundary, involving a combination of sudden as well as stepwise removals of species, is consistent with the fragmentation of a large comet that became perturbed by Jupiter into an Earth-crossing orbit. The larger fragments strike the planet relatively rarely compared with smaller bolides, the latter presumably arising from subsequent fragmentation events. The extinction of the dinosaurs 65 m yr ago probably resulted from a collision with a fragment that came under the Earth's influence some 1000 years before the fateful strike. Dust grains expelled from comets during their active lives shroud the Earth in a dust veil of variable density. Recent data on iridium and extraterrestrial amino acid deposits near the K/T boundary are also qualitatively explained.

THE DYNAMICAL PROPERTIES OF NEAR-EARTH OBJECTS

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After a brief review of the observational and orbital charactistics of near-earth asteroids and comets, the process of identifying potential threats to the earth is examined in terms of the available observational data, the mechanisms of search and follow-up and the dynamical principles involved. Particular emphasis is placed on the initial assessment of a possible hazard and on the danger of relying on a completely probabilistic approach to the hazard problem. The situation with regard to the threat posed by Comet Swift-Tuttle is updated.

Predicting Close Earth Approaches of Asteroids and Comets

Donald K. Yeomans
Jet Propulsion Laboratory/California Institute of Technology

The motions of all known Earth approaching asteroids and comets with reasonably secure orbits have been numerically integrated forward in time to A.D. 2200. Special care was taken to use the best available initial conditions including orbits based upon radar data. Each object was integrated forward with Earth and moon perturbations treated separately, with general relativistic equations of motion and with perturbations by all planets at each integration step. For the active short-period comets whose motions are affected by the rocket-like effects of vaporizing ices, a nongravitational force model was employed. When a close approach to the Earth was sensed by the numerical integration software, an interpolation procedure was used to determine the time of the object's closest approach and the minimum separation distance at that time. For those objects making the closest Earth approaches in the next two centuries, an error analysis was conducted to determine whether or not the object's error ellipsoid at the time of closest approach included the Earth's position (e.g. an Earth collision could not be ruled out). Although there are no obvious cases where a known near-Earth asteroid or comet will threaten the Earth in the next two centuries, there are several objects that warrant special attention. The Aten type asteroid 2340 Hathor makes repeated close Earth approaches and because most of its orbit lies within that of the Earth, it is often a difficult object to observe in a dark sky. For both asteroids and comets, there are generally dramatic increases in their position uncertainties following close planetary encounters.

Because of their short observational data intervals, their unmodeled nongravitational effects, and the possibility of escaping early detection by approaching the Earth from the sun's direction, long-period comets may present the largest unknown in assessing the long-term risk of Earth approaching objects. Fortunately the frequency with which these objects approach the Earth is very small compared with the numerous approaches by the population of near-Earth objects with short periodic orbits. For the short period comets, rocket-like outgassing effects and offsets between the observed center-of-light and the comet's true center-of-mass can introduce large uncertainties in their long-term orbital extrapolations. The uncertainty in the future motion of an active short period comet is substantially larger than the motion of an asteroid with a comparable observational history. While asteroids dominate the list of close Earth approaches in the next two centuries, their motions are relatively predictable when compared to the active comets.

For the rapidly growing population of known near-Earth asteroids and comets, efficient procedures are suggested for monitoring their long-term motions and making early predictions of future close Earth approaches.

Australasian Near-Earth Object Programs

Duncan Steel
Anglo-Australian Observatory

Major Australian involvement in NEO search efforts began in 1990 when the Anglo-Australian Near-Earth Asteroid Survey (AANEAS) started operations. We search all plates and films taken with the 48-inch UK Schmidt Telescope at the AAO for suspicious asteroid/comet trails, then performing follow-up using the UKST, the Uppsala Southern 50cm Schmidt Telescope or the Australian National University 40-inch reflector, all of which are situated at the Siding Spring Observatory about 350 km north-west of Sydney. To date about three dozen NEOs have been identified in the AANEAS program, and many dozens of other significant objects have been recovered or had astrometric positions determined.

The AANEAS program is now being expanded since additional government funding has been obtained which will assure operations at least until the end of 1995. We are planning to start using the UKST for 4/5 nights around bright-of-moon, when it is not normally operated, to obtain dedicated short-exposure films in pairs for examination in a stereo comparator. Preliminary analysis of the potential of this technique, compared to our present operations, indicate that a discovery rate of at least 30 NEOs per year should be achievable.

Apart from the AANEAS program, there are also significant follow-up capabilities elsewhere in Australasia. Notably at both the Perth Observatory in Western Australia and the Mount John Observatory in New Zealand astrometric follow-up is performed using 24-inch reflectors and astrographic cameras at each. In terms of an international search and follow-up program all three locations mentioned above are of importance in view of their latitudes and longitudes. There are also moves to build a major new observatory at a site in the Flinders Ranges of South Australia, which would fill the longitude gap between Siding Spring and Perth.

ABSTRACT FOR ERICE MEETING

THE COSMIC IMPACT HAZARD: OVERVIEW

David Morrison, NASA Ames Research Center
Chair, NASA International NEO Detection Survey

Cosmic impacts pose a significant hazard of loss of human life and property. Large but very infrequent impacts, primarily by asteroids, can produce short-term climate effects that endanger world food supplies and might lead to the death of a substantial fraction of the Earth's population. Analysis has shown that there is significant impact risk from both asteroids and comets in the size range from a few tens of meters diameter (about 10 MTn energy) up to the 15-km size of the K/T impactor (100 million Mtn). The lower threshold for danger is defined by the atmosphere of the Earth, which effectively shields us from impacts by projectiles less about 10 MTn energy. Above this threshold, an incoming asteroid or comet can penetrate to the lower atmosphere or surface and explode with sufficient force to devastate a large city. Fortunately, however, most such impacts -- like the 1908 Tunguska blast -- will not strike in densely populated parts of the world. From current statistics of asteroids and comets, we estimate that such an impact occurs over land about once per millennium, and that we might expect a major city to be destroyed by such an impact about once per 100,000 years. Of greater concern would be impacts in the oceans, which could raise tsunamis that would endanger coastal populations.

The greatest risk is associated with still larger impacts capable of causing global ecological catastrophe. Above some threshold -- estimated as lying between projectile diameters of 1 to 3 km -- impacts can produce global effects in addition to their immediate blast damage. Widespread crop failures would lead to starvation and epidemics. If such a impact took place anywhere on Earth during our lifetimes, we would each be in danger, independent of where the projectile struck. Statistical estimates of human risk associated with global ecological catastrophe suggest that each human on this planet runs a risk of perhaps 1 in 20,000 of dying from this cause as opposed to all of the other natural or accidental causes of death.

Prudence suggests that we should be concerned about such impacts and seek ways of avoiding them or mitigating their consequences. The primary objective of any program to deal with this hazard is to determine whether or not such a near-term impact is likely. The best approach is a comprehensive international telescopic survey that makes use of the most recent advances in detectors and automatic data processing to find faint moving objects and track them against the background of millions of stars. At the end of the survey we would know whether any near-Earth asteroid with diameter greater than 1 km poses a danger to us. If we find one or more threatening objects, we would have decades of warning in which to plan ways to deflect or destroy it.

LARGE BODY IMPACTS & MASS EXTINCTION EVENTS: EVIDENCE FROM THE CRETACEOUS/TERTIARY BOUNDARY AND A POSSIBLE GENERAL RELATIONSHIP

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The boundary between the Cretaceous and the subsequent Tertiary Period (the so-called K/T boundary; ~65 Myr ago) is marked by the mass extinction of some 75% of the species of marine organisms, and the total extinction of the dinosaurs. Discovery of anomalous concentrations of iridium and other trace elements in a thin globally distributed clay-rich layer that occurs in geologic sections coincident with the K/T boundary was followed by reports of diagnostic shock-deformed minerals, microspherules of various kinds, glassy microtektites and tektites, micro-diamonds, stishovite, etc. The evidence is now overwhelming that the basal few mm of the clay layer represents ejecta from the impact of a large asteroid or comet (~10 km diameter) on the earth. A large (~200 km diameter) candidate crater, the Chicxulub impact structure in northern Yucatan has been dated at 65.2±0.4 Myr, and the smaller (40 km) Manson crater in Iowa has the same age.

In the most detailed sections, the K/T boundary is marked by extinctions that were in general abrupt and without warning (including the dinosaur extinction), negative shifts in carbon- and oxygen-isotope ratios that indicate a severe loss of biomass and decrease in ocean productivity, and a climate warming of ~8°C in the first few thousand years of the Tertiary. Productivity seems to have been suppressed in the oceans for up to 1 Myr after the impact. Soot in the boundary layer indicates burning of a significant portion of the terrestrial biomass. In sections on land, abrupt extinction of Cretaceous floral elements at the boundary is followed by a fern-spore spike, indicating colonization of a devastated environment. The cause of the extinctions is most probably related to the environmental effects of the impact(s) including darkness, abrupt cooling, acid rain, the wildfires, poisoning by toxic substances, climatic fluctuations, etc. The mass extinction was followed by rapid adaptive radiation of new species to fill niches vacated by the groups that suffered extinction.

A convergence of evidence suggests that the biosphere may be a sensitive detector of large impact events, which result in the recorded global mass extinction pulses. The record of mass extinctions over the last 600 Myr is composed of a number of peaks (~23) of extinction pulses above background levels of extinction. A comparison of extinction rates and severity with the record of impact events provides a straightforward and general relationship—the larger the impact, the greater the mass extinction. A lower limit seems to exist, as impacts producing craters ≥50-60 km wide are not associated with global extinction pulses above background levels.

A number of extinction boundaries studied in some detail show abrupt changes in biota and isotopes similar to those at the K/T boundary, and some show stratigraphic evidence of large impacts— shocked quartz, microtektites/tektites, and/or Ir anomalies, although the Ir anomalies are usually small and may indicate impacts of Ir-poor, but energetic, comets The largest known craters have a significant correlation with the extinctions, including Manicouagan (~100 km wide), close to the end-Triassic; Doulon in China (~80 km) near the Triassic/Jurassic boundary, Popigai (~100 km) near the Eocene/Oligocene transition, and Chicxulub (~200 km) at the K/T boundary. Newly proposed impact structures on the Falkland Plateau (~350 km and 200 Km) apparently correlate with the end-Permian extinction (~250 Myr), the most severe in the last 600 Myr.

Historical perspectives on impact hazards

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Abstract Unexpected fragmentations in the Taurid cometary-asteroidal stream appear to be responsible for most major enhancements of the fireball flux these last 2,000 years[1][2]. The stream is the probable cause therefore of man's repeated expectation during this period that the "last times" were imminent[3]. Arising from this fact, the stream is thus perceived as the likely direct *and* indirect cause of the increased social disorder during these enhancements, which contemporaries recognised as leading to war and revolution. When the cause was correctly perceived as indirect, presupposing no cosmic interference in terrestrial affairs in opposition to more traditional astrological doctrine, the imposition of political constraints on astronomical predictions was certainly reasonable. However it is difficult to see how this could have been anticipated with certainty in advance and it is demonstrably unsatisfactory that astronomers now unwittingly discount future enhancements of the fireball flux, not altogether without risk so far as civilization is concerned. Indeed the frequency of these enhancements is an indication that it may not be wise to relax in the presence of the Taurids.

References

(1) Bailey, Clube, Hahn, Napier & Valsecchi 1993 *Chirons and Halley-type chaotic orbits*, Tucson Proceedings.

(2) Steel, Asher, Napier & Clube 1993 *Coherent Catastrophism*, Tucson Proceedings.

(3) Clube 1993 *Hazards from space: comets in history and science* in "How science works in a crisis: the mass extinction debate" (ed Wm. Glen, Stamford Univ. Press).

Research Activities on Asteroids and Comets

conducted in Japan

S.Yabushita (Kyoto Univ.)

Abstract

Review is made of the current research on asteroinds and comets conducted in Japan. Of particular interest in relation to the object of the meeting is observational activities of A-A type asteroids. Current observational activities are reviewd.

As to the future programmes, two proposals have been made to improve the present observational activities of NEO detections. Of these,one is likely to be realized in a not too distant future.

It is imporatant that the nation as a whole be persuaded of the seriousness of the hazrd from space,and publications of the subject matter in the media appears of particular importance in Japan. Books dealing with the subject (published and in the press) are reviewed.

PHYSICAL AND CHEMICAL PROPERTIES OF NEAR-EARTH OBJECTS

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ABSTRACT

The effects of entering cometary and asteroidal bodies on the Earth's surface environment are strongly dependent on the physical properties of the entering objects, the geometry of their entry into the atmsophere, and their entry velocity. Our ability to detect ancient impacts depends upon the above physical properties and also upon their chemical composition, which may leave a distinctive geochemical "signature" in contemporary sediments. Large entering objects that do not have a distinctive geochemical signature, or which eject much of the mass of the impactor by explosive blowoff at speeds above escape velocity, will be strongly under- represented in our cratering record. A survey of the physical and chemical properties of near-Earth objects, including meteorites, fireballs, near-Earth asteroids, and both long- and short-period comets (with discovery bias corrections applied wherever possible) has been conducted in support of a Monte Carlo model of the modern-day impact bombardment of the terrestrial planets. The mass distributions, densities, spectral classes, chemical compositions, crushing strengths, and luminous efficiencies of these near-Earth objects and the distribution of these properties over orbital parameters are surveyed. The implications of these properties are explored with respect to crater formation; iridium signatures, blast-wave NO_x production, air burst blast-wave intensities, fire ignition, and blowoff of impactor material are briefly surveyed with contemporary impact hazards in mind.

SEARCH FOR NEAR-EARTH OBJECTS WITH

GROUND-BASED ELECTRO-OPTICAL DEEP SPACE SURVEILLANCE (GEODSS) ASSETS

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This is a brief review of plans and current status of the adaptation of an Air Force wide field GEODSS telescope for the discovery and followup of Near-Earth Objects (NEOs). The proposed search program will focus on the discovery of natural objects and will proceed on a non-interference basis, avoiding any impact on GEODSS' dedicated purpose of tracking and monitoring Earth orbiting spacecraft.

JPL representatives had an initial meeting in September 1992 with GEODSS personnel and toured their facilities in Maui. GEODSS telescopes were discussed in terms of using these existing sensors for the detection of NEOs. A result of these meetings was a test run at the GEODSS, Socorro, New Mexico site to evaluate the tracking and astrometric accuracy of a close approach of NEA, (4179) Toutatis. In mid-December at Socorro the passage of Toutatis was observed. Data was obtained with GEODSS' 1-M telescopes and the observed positions were compared with the precise ephemeris. Position measurements were acquired to an accuracy of 2-3 arcseconds. Although not quite adequate for astrometric observations, the results were better than anticipated based upon the current Ebsicon (silicon intensifier tubes) system. If an agreement is reached to use these Air Force assets, these older systems would be replaced with Charged Couple Devices (CCDs) which would provide the necessary accuracy for a NEO discovery program.

In January 1993, a presentation was made at Peterson Air Force Base in Colorado Springs, Co. to top level Air Force personnel who have administrative oversight of all of the Air Forces's GEODSS telescope facilities in Maui, Socorro, and Diego Garcia. A review was presented of the results from the Toutatis tracking and astrometry tests. We proposed and requested further access for evaluation of the GEODSS system so plans could proceed if no major difficulties were identified. In parallel, with this request, we inquired whether a decision could be made by U.S. Space Command for access to GEODSS and that we be permitted to use the Air Force system in an updated version of their present configuration.

JPL received approval in March 1993 from the U. S. Space Command to use the GEODSS assets with the understanding in so doing, that there would not be significant impact on their military space surveillance mission. The Air Force has requested details of our requirements and have indicated that they are prepared to work with us to resolve any issues associated with our use of the GEODSS sensors.

With plans to proceed with the GEODSS CCD upgrade, JPL is currently organizing the overall project, identifying key personnel and setting dates to meet with appropriate Air Force, Phillips Laboratory and LLNL personnel.

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